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Efficient visual search for multiple targets among categorical distractors: Effects of distractor–distractor similarity across trials

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ABSTRACT

We trained one group of pigeons to search for members of an artificial category among category-unspecified nonmembers. For another group of pigeons, the roles of the targets and of the distractors were reversed. Experiment 1 found that the latter group showed surprisingly efficient search for multiple nonmembers. Search times in this group were generally faster than those in the former group, regardless of the display size. In Experiment 2, search efficiency of the former group decreased with novel, poor, exemplars of the target category, whereas the latter group continued to exhibit efficient search for the nonmembers among novel members of the category. The former group eventually developed efficient search for all the targets through practice, but search time remained longer than in the latter group. These findings suggest that distractor–distractor, not target–target, similarity across trials facilitates search for multiple targets, by enhancing target salience relative to global contextual background of search scene.

1. Introduction

When we look for something special, it is easier to find it across search scenes that are the same or similar to each other than in ones that shift from time to time. This might be a factor even for animals that frequently visit certain foraging fields where they efficiently search for edible items fairly easily under similar circumstances. The present study examines the effect of similarity of background scenes on visual-search performance.

In our previous study (Ohkita & Jitsumori, 2012), we used members of an artificial category as targets and category-unspecified nonmembers as distractors for pigeons in a visual search task. An artificial category was created by morphing human faces. As shown in the upper part of Fig. 1, one face (Face P) was morphed with each of the remaining four faces (Faces A, B, C, and D, with the letters arbitrarily assigned to the four faces) to create composite faces AP, BP, CP, and DP. We also created 50% morphs of possible pairings of A, B, C, and D (AB, AC, AD, BC, BD, and CD) each of which was then morphed with P to create additional composite faces. For example, by blending AB and P, a three-component composite face ABP was created. The composite faces connected with broken lines in Fig. 1 have the same proportion (50%) of Face P which functions as a common component in this category. Faces A–D, as well as Faces AB–CD, are the item-specific components, all of which were used to create individual exemplars of this face category. Face P (P% = 100) and an item-specific component face (P% = 0) reflect, respectively, two extreme exemplars along the corresponding face-morph dimension, although the category as a whole is characterized by Face P.[1] The lower part of Fig. 1 shows the category-unspecified nonmembers.

In a series of experiments by Ohkita and Jitsumori (2012), pigeons were trained to search for the composite faces (P% = 50) among the nonmembers. Eventually, they revealed a highly efficient search (i.e., the slope of reaction time over the number of distractors was near zero) in a condition where a nonmember distractor item appeared repeatedly to form the background of given search display, with the particular nonmember item varying from trial to trial. The pigeons then transferred their efficient search to the novel members having larger proportions of the common component, including the original face used as the common component (Face P). Search efficiency dramatically decreased as

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[1] In our categorization study (Jitusmori, Ohkita, & Ushitani, 2011), pigeons were trained in a go/no-go procedure to discriminate exemplars from two categories created similarly to the category used in the present study. The pigeons then showed a generalization gradient that increased as a function of the proportion of the common component of the positive category, with the best discrimination emerging for the untrained common component faces of the positive and negative categories. Based on this finding, we define the original face, which is the basis for morphing transformations, as the prototype of the category; this is Face P.

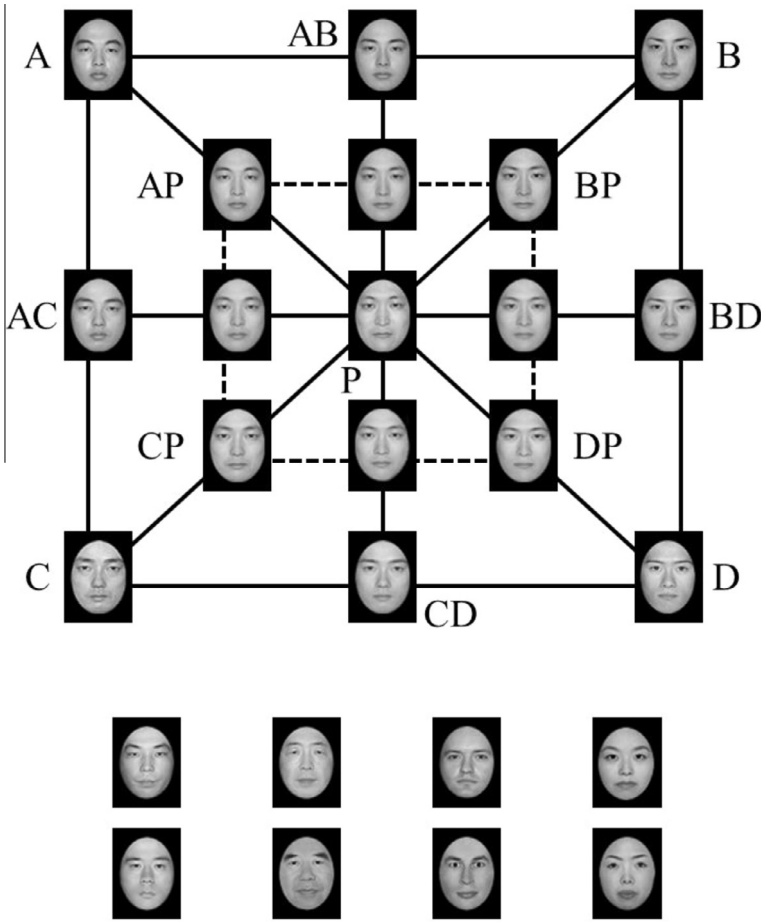

Fig. 1. Upper part: Grayscale reproduction of an artificial category. One face (Face P) arbitrarily selected from the five original faces was used as the common component of the category. The common component was morphed with each of the remaining four original faces (A, B, C, or D) and the 50% morphs of the possible pairs of these faces. Faces AD, BC, and those created by blending each of these faces with P are not shown. Lower part: Category-unspecified nonmembers.

the common component decreased to 25% and to 0% (the original faces used as the item-specific components A, B, C, and D), indicating that the pigeons searched for the targets primarily on the basis of common component features. The face used as the common component for one pigeon was used as an item-specific component for another pigeon and vice versa; therefore the effect was related to the structure of the category and not to specific properties of the face used as the common component. Moreover, because the face used as Face P for each pigeon was selected arbitrarily from a set of five original faces, the novel displays containing Face P and Faces A–D as targets could not be differentiated without a pigeon having acquired knowledge of the target category. Therefore, we concluded that an efficient search for Face P was accomplished by top-down control due to learning category information and not by bottom-up similarity relationships between targets and distractors within search displays.

In the present study, one group of experimentally naïve pigeons, the C-N (Category Targets among Non-category Distractors) group, were trained to search for the good members (P% = 50) of the category among the nonmembers, as in Ohkita and Jitsumori (2012). For another group of pigeons, the N-C (Non-category Targets among Category Distractors) group, the target–distractor roles were reversed. Fig. 2 illustrates examples of the search stimuli used in the C-N (left panels) and N-C (right panels) tasks. The target and distractor sets were thus not interchanged for the same pigeon, thereby preserving a constant mapping of stimuli to response. The present study examined the search strategy adopted by each of these groups and compared its impact on search performance. The training and testing procedure was the same for the two groups, thereby equating learning history, except that the roles of the targets and of the distractors were reversed between the groups.

In a categorization study with humans, Corneille et al. (2006) used category exemplars that comprised a series of faces that were located along the left end or the right end of a continuum of morphed faces. Participants learned to classify exemplars into a reference category (i.e., a category labeled "club members" consisted of exemplars lying either at one end or the other of a continuum) and a non-reference category (i.e., a category labeled "not club members"). After learning these categories, participants were tested in a visual search task. They showed better detection of the reference category items than of the non-reference category items among novel, category-unspecified, original faces. Corneille et al. argued that membership in the reference category acts as a salient feature that increases detection of the faces in this category, compared with the non-reference category faces that are defined merely as lacking this feature.

Search asymmetry studies, where the roles of targets and of distractors are reversed, often find that the presence of a feature is more salient than its absence (e.g., Treisman & Gormican, 1988; Treisman & Souther, 1985). For example, the search for an intact circle among circles with an intersecting line is more difficult and less efficient than the other way around. That is to say, looking for the presence of a feature (a line in this case) is easier than looking for its absence, as far as the targets and distractors are clearly differentiated by the presence vs. absence of a feature. Treisman

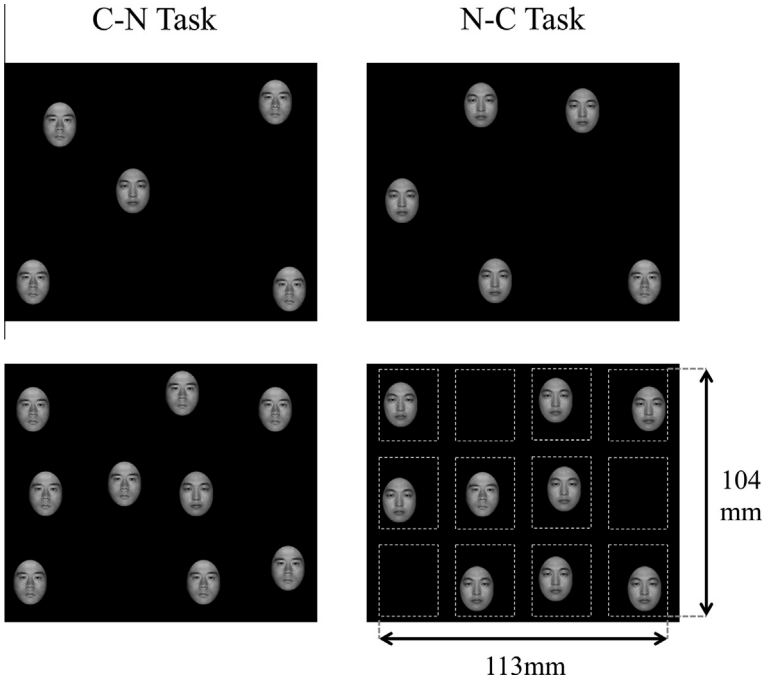

Fig. 2. Gray scale reproduction of examples of the search stimuli used in the C-N (left panels) and N-C (right panels) tasks. Each item was presented in an invisible rectangle (a touch-sensitive area) illustrated by the dotted lines in the bottom-right panel. The 3 × 4 stimulus array (104 mm × 113 mm) located at the center of the viewing window (not shown here).

and Gormican (1988) applied a similar logic to the finding that searches for a curved or tilted line among straight ones are easier than searches for a straight line among curved or tilted ones. They argued that the curved or tilted lines are coded as straight or vertical lines with an additional feature marking the nature of the deviation, just as the circle with the added line is coded as the standard circle with an additional feature (the intersecting line).

The face stimuli used as the targets and distractors in the present study can be differentiated clearly by the presence vs. absence of the common facial component of the category. Possibly, the Group N-C pigeons search for the targets (i.e., the category-unspecified nonmembers) relying on the absence of the Face P component. However, it might be easier for animals to learn to approach a stimulus that has a critical feature than to approach the stimulus that lacks it (the so-called feature-positive effect; Jenkins & Sainsbury, 1970). It is likely that the pigeons in this group search for the targets on the basis of the representations of individual nonmembers or the features that are specific to each of these faces. Searches for multiple targets that are not particularly similar to one another, as with targets of Group N-C, are often inefficient when the target appearing on a given trial is unknown in advance (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; also see Vreven & Blough, 1998, in pigeons).

Both of these considerations led us to predict that searches by Group N-C would more difficult and less efficient than searches by Group C-N. To preview the result, Group N-C showed surprisingly efficient search in Experiment 1, with search times generally faster than those of Group C-N. This finding is clearly not consistent with our original prediction. Accordingly, Experiment 2 was designed to explore the possibility of transfer of search performance to various exemplars with different proportions of the common component. The aim was to examine whether the common component of categorical distractors may guide attention away from the distractors in Group N-C. A byproduct of this negative guidance would be a search directed toward the target, resulting in an efficient search for the category nonmembers that are not particularly similar to one another (see Chun & Jiang, 1998; Kristjánsson & Driver, 2008; Woodman & Luck, 2007; Yang, Chen, & Zelinsky, 2009, for distractor-related guidance in humans). A question of interest is whether search efficiency decreases as the proportion of the common component of the distractors decreases in Group N-C.

In addition, the effect of practice on search performance is explored in Experiment 2. Shiffrin and Schneider (1977) have claimed that, when a target category is well-learned, due to much practice, categorical information will automatically guide search in the absence of controlled allocation of attentional resource. In line with this claim, Ohkita and Jitsumori (2012) found that practice produced efficient search for a variety of members of the target category, including the original faces used as the item-specific components (Faces A, B, C, and D). A question of interest of the present study is whether and to what extent practice improves search performance in Group N-C.

2. Experiment 1

Experiment 1 compared search performance measured by accuracy and reaction time (RT) between Group C-N and Group N-C. The pigeons received training with search displays consisting of one target and four identical distractors; display size (DS) was 5. They were then tested on DSs of 5 and 9. We used only two values, because pigeons in our previous study showed a systematic increase of RTs with increasing DSs of 3, 5, 7, and 9 (Experiment 1, Ohkita & Jitsumori, 2012), which led us to infer that the DSs of 5 and 9 would allow us to estimate search efficiency reliably for comparisons between the groups.

Another question addressed the target–distractor similarity effect. It has been repeatedly documented that search efficiency decreases with increasing similarity between targets and distractors, by using non-categorical items for humans (Duncan & Humphreys, 1989) and pigeons (Blough & Blough, 1997). The category used in the present study was created from faces of Japanese male students only, whereas the category-unspecified nonmembers differed in terms of ethnic affiliation, sex, and age, i.e., they were

Japanese male students, Japanese male professors, Caucasian male students, and Japanese female students (see Fig. 1). Ohkita and Jitsumori (2012) found that search slope for the categorical targets did not differ depending on the face class used as the distractors; distractors that were presumably more similar to the targets (Japanese male students) did not slow the search speed but simply added a constant to RT. The well-known target–distractor similarity effect was thus not obtained, a finding supporting the conclusion of Ohkita and Jitsumori (2012) that the common component directed the pigeons' attention to the targets, regardless of the target–distractor similarity in the displays. If the Group C-N pigeons learned to search for the targets relying on the common component, as did the pigeons in the Ohkita and Jitsumori study, then they would show no target–distractor similarity effect in the present study. By contrast, if the Group N-C pigeons searched for the individual nonmembers, the target–distractor similarity would substantially control search efficiency in this group.

2.1. Method

2.1.1. Animals

Eight experimentally naïve pigeons were randomly allocated in equal numbers to the two groups at the start of the experiment. They were maintained at 80–85% of their free-feeding weights throughout the experiment. Water and grit were freely available in their individual home cages.

2.1.2. Apparatus

The apparatus was the same as that used in Ohkita and Jitsumori (2012). Four identical chambers were used, one for each pigeon in a group. Stimuli were presented on LCD color monitor (EIZO FlexScan L367), visible through a viewing window (150 mm high × 200 mm wide) located in the middle of the front panel. The monitor was located 1.5 cm behind an infrared touch frame (Carrol Touch, Model 3467). A food aperture located below the viewing window afforded pigeons access to a food tray. A houselight (3 W) dimly illuminated the chamber.

2.1.3. Stimulus materials

The category created individually for each pigeon in Ohkita and Jitsumori (2012), using commercially available morphing software (Morph, Gryphon), was used for each of four pigeons in a group. Category nonmembers were also identical to those of the previous study; two Japanese male students other than those used to create the categories, two Japanese male professors, two Caucasian male students, and two Japanese female students.

There were 12 touch-sensitive rectangles (100 pixels high × 80 pixels wide) of a 3 × 4 array, with two adjacent rectangles separated 25 pixels vertically and 20 pixels horizontally on the monitor (see the bottom-right panel of Fig. 2). Each stimulus (64 pixels × 48 pixels, where one hundred pixels corresponds to 29.7 mm on the monitor) was presented in a touch-sensitive rectangle, so that the stimuli did not lie in orderly rows or columns and any two stimuli were not closer than 41 pixels vertically and 32 pixels horizontally. The target and distractors were pseudo-randomly distributed in a given display, with the constraint that the targets appeared in each of the 12 touch-sensitive rectangles with approximately equal probability within each session.

2.1.4. Procedure

Following magazine training, the pigeons learned, through conventional hand-shaping, to peck at a warning stimulus (a white cross) presented at the center of the screen. The birds were then trained to peck target items. Only one target could appear on a given trial, with each target appearing equally often in a session of 40 trials for each group. A response to the target blackened the display and immediately delivered food (the food hopper was presented for 3 s). Food presentation was followed by the intertrial interval (ITI) of 3 s, during which the houselight illuminated the chamber. All birds received at least three sessions.

2.1.4.1. Initial training. Once responses to individual targets had been established, we introduced the distractor items; a peck to the warning stimulus produced a search display consisting of one target and four identical distractors. Responses to distractors were ineffective and the search display remained on until the pigeon responded at the target; the display was terminated by a response at the target which was followed immediately by food reinforcement. When the pigeon's first peck occurred to the target, the trial was scored as correct. When the pigeon pecked at the distractor(s) before pecking at the target, the trial was scored as incorrect. There were 80 displays (10 targets × 8 distractors for Group C-N, 8 targets × 10 distractors for Group N-C), each of which appeared once in two consecutive sessions (with 40 trials per session). This training phase continued until the pigeons performed 75% correct or more accurately in each of two consecutive sessions. If a pigeon failed to reach the criterion, this training phase terminated after 28 sessions.

2.1.4.2. Final training. A response to a distractor (error) produced a 2-s blackout and then an ITI of 3 s began. The same trial was repeated until the pigeon responded correctly to a given target. Correction trials were not counted in the total count of trials and performance scores. Training continued until the pigeons performed an overall accuracy of at least 75% correct in two consecutive sessions (40 trials per session), during which each of the 80 displays appeared once as before.

Next, the probability of reinforcement was decreased gradually and more trials were added. The number of trials per session was increased to 80, 120, and up to 160. In the final phase of training, a session consisted of 16 blocks of 10 trials for Group C-N and 20 blocks of 8 trials for Group N-C, respectively. Each target appeared once in a block, with the sequence of targets randomized in each block. Four identical distractors were pseudo-randomly selected on each trial under the constraint that each of the 80 target–distractor pairs appeared once in the first half and once in the second half of a session of 160 trials. A response to the target was reinforced on the predetermined 40 trials, with the probability of food rewards equated among the targets within and across sessions in each group. Correct responses on the remaining trials raised the food hopper for only 0.5 s. Training continued until the pigeons achieved an accuracy of 90% correct or better in each of two consecutive sessions. If a pigeon failed to reach this criterion, the final phase training terminated after 20 sessions of 160 trials each. Other procedural details were the same as in the initial training.

2.1.4.3. Testing with different display sizes. The pigeons were tested on DSs of 5 and 9. There were 160 displays (10 targets × 8 distractors × 2 DSs for Group C-N, 8 targets × 10 distractors × 2 DSs for Group N-C), each of which appeared once in a session. As in the final training, a session consisted of 16 blocks of 10 trials for Group C-N and 20 blocks of 8 trials for Group N-C, respectively. A given target–distractor pair appeared once in the first half and once in the second half of a session, with the display size varied between the two trials. The sequence of the DSs was randomized with the restriction that the DSs 5 and 9 occurred equally often in a block for each group. The pigeons received eight test sessions. Other procedural details, including the correction method, were the same as in the final training.

2.2. Results and discussion

2.2.1. Initial training

Two of the four pigeons in Group C-N reached the performance criterion (75% or better accuracy in each of two consecutive sessions); they required 8 and 14 sessions, respectively. The remaining two pigeons in this group failed to reach the criterion and the training terminated after 28 sessions; they both performed 60% correct on average in the last two sessions. The four pigeons in Group N-C learned the search task relatively quickly; they took 11, 14, 17, and 17 sessions, respectively, to reach the performance criterion.

2.2.2. Final training

The Group C-N pigeons required an average of 7 sessions (range: 2–10 sessions) to attain 75% correct or better over two consecutive 40-trial sessions (the accuracy averaged among the four pigeons was 78%). On the other hand, the Group N-C pigeons performed accurately and they received only two 40-trial sessions (the accuracy averaged among the four pigeons was 77%).

Next, the number of trials per session was increased gradually up to 160 trials. Only two pigeons, one from Group C-N and one from Group N-C, reached the final criterion (90% correct or better in each of two consecutive 160-trial sessions). The remaining pigeons failed to reach the final criterion and training terminated after 20 sessions of 160 trials each; mean accuracy in the last two sessions for these pigeons was 83% (range: 77–87%) in Group C-N and 85% (range: 83–88%) in Group N-C.

2.2.3. Testing with different display sizes

The RT on a given trial was defined as the time between onset of the display and the correct response, with reaction times of less than 100 ms eliminated from consideration (the percentage of trials with such RTs was less than 0.11% of the total).

For each of the four face classes used as the distractors for Group C-N and as the targets for Group N-C, the median RT at a given DS was computed for each pigeon on the basis of 160 observations (20 observations × 8 sessions). Fig. 3 compares the display-size functions in accuracy (top panels) and RT (bottom panels) for the four face classes in each of Group C-N and Group N-C. Data points are averages among four pigeons in a group. We conducted a two-way repeated measures analysis of variance (ANOVA), with face class and DS as within-subject variables, on both accuracy and RT data from each group. In these and all other tests, an alpha level of .05 was used.

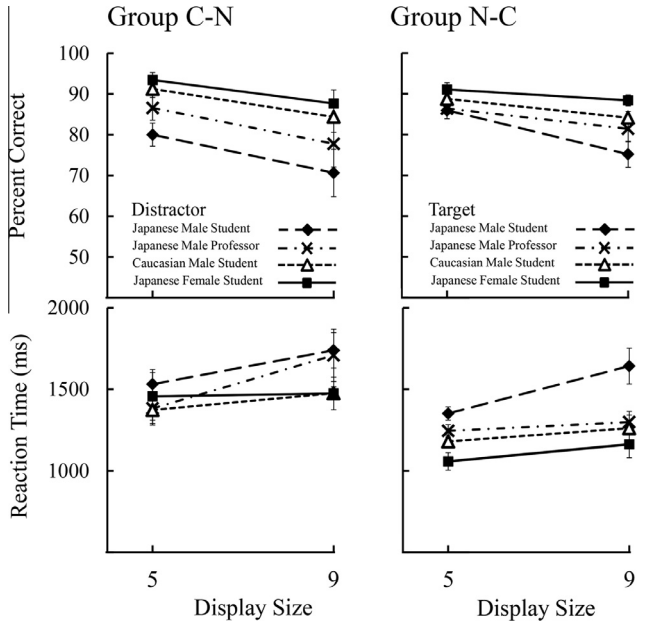

Fig. 3. Mean search accuracies (top panels) and reaction times (bottom panels) for display sizes of 5 and 9, shown separately for the four classes of distractors in Group C-N and of targets in Group N-C. Error bars show standard errors.

Group C-N. Search accuracy differed as a function of the face class. In order of accuracy, the magnitudes (lowest to highest accuracy) were: Japanese male student < Japanese male professor < Caucasian male student < Japanese female student. The effect of face class [$F(3,9) = 12.37$, $p = .002$, $\eta_p^2 = .81$] was significant. Fisher's LSD revealed that the Japanese male student face significantly decreased accuracy, relative to that of the Japanese female student ($p < .001$), the Caucasian male student ($p < .01$), and the Japanese male professor ($p < .05$). Also, the Japanese male professor face significantly decreased accuracy, relative to that of the Japanese female student ($p < .05$). The effect of DS [$F(1,3) = 7.97$, $p = .067$, $\eta_p^2 = .73$] was marginally significant. The interaction [$F(3,9) = 1.27$, $p = .341$, $\eta_p^2 = .30$] was not significant.

The effect of face class on RT [$F(3,9) = 4.33$, $p = .038$, $\eta_p^2 = .59$] was significant. Fisher's LSD revealed that the Japanese male student face significantly increased RT, relative to that of the Japanese female student ($p < .05$) and the Caucasian male student ($p < .01$). The effect of DS [$F(1,3) = 12.99$, $p = .037$, $\eta_p^2 = .81$] was significant. However, the interaction of these variables [$F(3,9) = 2.97$, $p = .090$, $\eta_p^2 = .50$] was not significant; search efficiency did not differ depending on the face class used as the distractors. This finding is consistent with the conclusion of Ohkita and Jitsumori (2012) that the common component directed pigeons' attention to the targets.

Group N-C. An effect of face class on accuracy was observed which resembles that found in Group C-N, although this tendency was not apparent at DS = 5. The effect of face class [$F(3,9) = 7.11$, $p = .010$, $\eta_p^2 = .70$] was significant. The effect of DS [$F(1,3) = 7.85$, $p = .068$, $\eta_p^2 = .72$] was marginally significant. The interaction [$F(3,9) = 4.57$, $p = .033$, $\eta_p^2 = .60$] was significant, reflecting the finding that, when DS increased to 9, the detection of the Japanese male student face decreased more markedly, compared with the other face classes.

The search was fast, except when the Japanese male students appeared as the targets. The effect of face class [$F(3,9) = 29.21$, $p < .001$, $\eta_p^2 = .91$] was significant. The effect of DS was marginally significant [$F(1,3) = 6.74$, $p = .081$, $\eta_p^2 = .69$]. The interaction [$F(3,9) = 5.53$, $p = .020$, $\eta_p^2 = .65$] was significant, suggesting that search efficiency differed depending on the face class used as the targets. Only for the Japanese male students, the simple main effect of DS was significant [$F(1,12) = 20.62$, $p < .001$, $\eta_p^2 = .63$], a finding consistent with the target–distractor similarity effect (Duncan & Humphreys, 1989). These results suggested that the pigeons in the N-C group searched for the individual nonmembers and that their searches were surprisingly efficient when targets and distractors were from different face classes.

Comparisons between Groups C-N and N-C. Overall accuracy did not differ between the groups (88% correct for the both groups at DS = 5; 80% and 82% correct for Group C-N and Group N-C, respectively, at DS = 9). On the other hand, Group N-C generally showed faster RTs than Group C-N. A two-tailed t test, performed separately for the DSs of 5 and 9 conditions, found a significant difference between the groups: $t(30) = 3.42$, $p = .002$, Cohen's $d = 1.21$ at DS = 5; $t(30) = 2.96$, $p = .010$, Cohen's $d = 1.04$ at DS = 9 ($N = 16$; 4 pigeons × 4 face-classes in each group). The searches for the category-unspecified nonmembers among the category members are faster than the reverse, a finding opposite to that predicted on the basis of current theories of visual search.

3. Experiment 2

How can we explain the finding in Experiment 1 that Group N-C showed surprisingly fast searches for the multiple nonmembers that are not particularly similar to one another? One possibility is that the categorical distractors aided the search for the individual nonmembers by guiding pigeons' attention away from the distractors (see also, for example, Yang, Chen, & Zelinsky, 2009, for negative-guidance by distractors in humans). A revised feature integration theory (Treisman & Sato, 1990) handles such a possibility with an assumption that inhibitory connections operate between individual feature maps and the master map. If distractor features are known in advance, then locations on the master map linked with distractor features can be actively inhibited, thereby enabling efficient search. Extending this theory to the categorical distractors used for Group N-C, we can predict that the common component of the distractors (P% = 50) facilitated the search for the category nonmembers. A question of interest in Experiment 2 is whether and to what extent search efficiency decreases as the proportion of the common component decreases.

3.1. Method

3.1.1. Animals and apparatus

The two groups of pigeons that served as subjects in Experiment 1 were used. Housing, maintenance, and apparatus were the same as in Experiment 1.

3.1.2. Stimulus materials

Five faces (P% = 0, 25, 50, 75, and 100) on each face-morph dimension ranging, respectively, from A, B, C, or D to P were used (face stimuli were prepared for individual pigeons as in Experiment 1). There are 20 stimuli (5 faces × 4 dimensions), including the four identical original faces used as P. Category nonmembers were the same as those used in Experiment 1.

3.1.3. Procedure

Experiment 2 began soon after the completion of Experiment 1. The pigeons were given 160-trial sessions with the DSs of 5 and 9, as in the test phase of Experiment 1. Training with the good members of the category (P% = 50) continued for a maximum of 12 days or until 90% or better accuracy was obtained in a session of 160 trials.

The pigeons were then tested with 160 different target–distractor pairs (20 targets × 8 distractors for Group C-N, 8 targets × 20 distractors for Group N-C), each of which appeared once in a session of 160 trials. The DS of a given target–distractor pair varied across two consecutive sessions (DS = 5 in one session and DS = 9 in the other session). This was repeated eight times, resulting in a total of 16 test sessions; there were eight 2-session blocks (Blocks 1–8).

Each test session consisted of 160 trials; eight blocks of 20 trials for Group C-N (each of the 20 targets appeared once per block) and 20 blocks of 8 trials for Group N-C (each of the 8 targets appeared once per block). The sequence of target stimuli was randomized in each block. The sequence of distractor stimuli was randomized under the restriction that each distractor appeared equally often within the first 80 trials as well as in the second 80 trials of a 160-trial session for each group. DSs 5 and 9 appeared equally often in each session.

3.2. Results and discussion

3.2.1. Training

Two pigeons in Group C-N and three pigeons in Group N-C reached the performance criterion of 90% correct or better. The remaining two pigeons in Group C-N and one pigeon in Group N-C performed at 73%, 88%, and 85% correct, respectively, in the last training session.

3.2.2. Testing

Search accuracy at a given DS in each of the eight 2-session blocks was computed for each pigeon, separately for the different proportions of the common component of the targets (Group C-N) or of the distractors (Group N-C). Fig. 4 shows the mean search accuracies as a function of 2-session block (Blocks 1–8), separately for the DSs of 5 and 9 in Group C-N (left panels) and Group N-C (right panels). Search accuracy was poor when the proportion of the common component decreased to 0%. This tendency is striking in the early sessions of Group N-C. Search accuracies across conditions appear to converge in later sessions.

3.2.2.1. Searches in early test sessions. We obtained the mean of median RTs in the first two 2-session blocks (Blocks 1 and 2) for each pigeon, separately for the different proportions of the common component. Fig. 5 shows the mean RTs averaged over the four pigeons within each group (bottom panels), together with the corresponding accuracy data (top panels). The RTs with the old target–distractor pairs (see the data designated P% = 50 in the bottom panels of Fig. 5) replicated the finding of Experiment 1 that search times in Group N-C were faster than those in Group C-N.

Group C-N. The pigeons performed accurately with the novel targets, except for the P% = 0 targets. A two-way repeated measures ANOVA, with display size (5 vs. 9) and morph proportion (0% vs. 25% vs. 50% vs. 75% vs.100%) as within-subject variables was applied on the accuracy data. The effect of morph proportion [$F(4,12) = 7.77$, $p = .002$, $\eta_p^2 = .72$] was significant. However, neither the effect of DS [$F(1,3) = 4.63$, $p = .120$, $\eta_p^2 = .61$] nor the interaction [$F(4,12) = 0.71$, $p = .601$, $\eta_p^2 = .19$] were significant. Fisher's LSD revealed that the P% = 0 targets significantly decreased accuracy, relative to the P% = 25 ($p < .05$), 50 ($p < .001$), 75 ($p < .001$), and 100 ($p < .01$) targets.

The search slopes for the P% = 0 and P% = 25 targets were steep (i.e., inefficient), whereas targets containing 50% (or greater) of the common component produced search slopes that were almost flat. A two-way repeated measures ANOVA found that the main effects [$F(4,12) = 12.70$, $p = .038$, $\eta_p^2 = .81$ for morph proportion; $F(1,3) = 8.99$, $p = .001$, $\eta_p^2 = .75$ for DS] were both significant. The interaction [$F(4,12) = 7.13$, $p = .004$, $\eta_p^2 = .70$] was also significant. The interaction reflects the finding that the simple main effect of DS was significant only for the P% = 0 targets [$F(1,15) = 23.13$, $p < .001$, $\eta_p^2 = .61$] and the P% = 25 targets [$F(1,15) = 14.29$, $p = .002$, $\eta_p^2 = .49$]. These results confirm that the categorical information supports the efficient search for the targets having 50% or larger proportions of the common component, in agreement with Ohkita and Jitsumori (Experiment 3, 2012).

Group N-C. Accuracy to search for the nonmembers decreased dramatically as the common component of the distractors decreased to 25% and to 0%. The main effects [$F(4,12) = 25.27$, $p < .001$, $\eta_p^2 = .89$ for morph proportion; $F(1,3) = 33.29$, $p = .010$, $\eta_p^2 = .92$ for DS] were both significant, however their interaction was not significant [$F(4,12) = 0.66$, $p = .634$, $\eta_p^2 = .18$]. Fisher's LSD revealed significant differences in accuracy between the P% = 0 and each of the P% = 25, 50, 75, and 100 distractors ($p_s < .001$). Also, the P% = 25 distractors significantly decreased accuracy, relative to the P% = 50 ($p < .05$), 75 ($p < .01$), and 100 ($p < .05$) distractors.

Surprisingly, RTs of correct responses were fast, regardless of the proportion of the common component of the distractors and DS. Neither the main effects [$F(4,12) = 0.52$, $p = .724$, $\eta_p^2 = .15$ for morph proportion; $F(1,3) = 5.15$, $p = .108$, $\eta_p^2 = .63$ for DS] nor the interaction [$F(4,12) = 0.64$, $p = .642$, $\eta_p^2 = .18$] were significant.

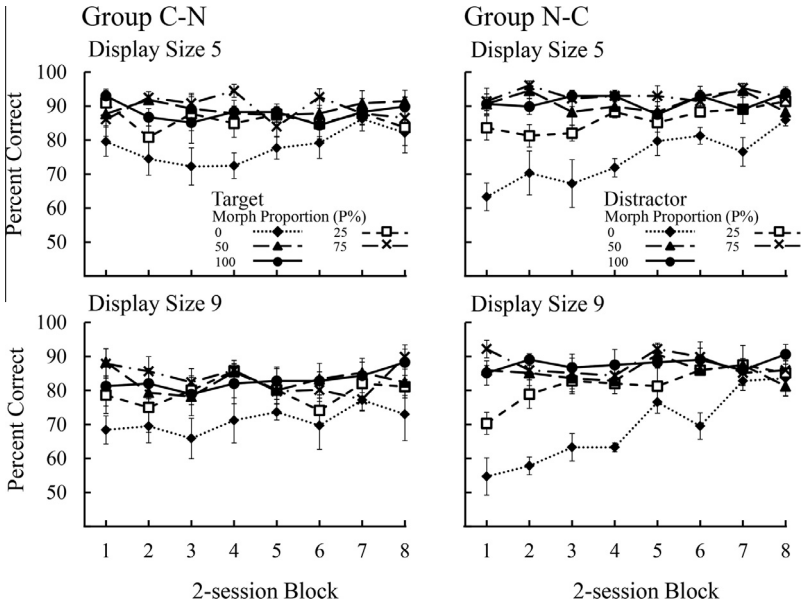

Fig. 4. Search accuracies as a function of 2-session block for display sizes 5 (top panels) and 9 (bottom panels) in Experiment 2. Error bars show standard errors.

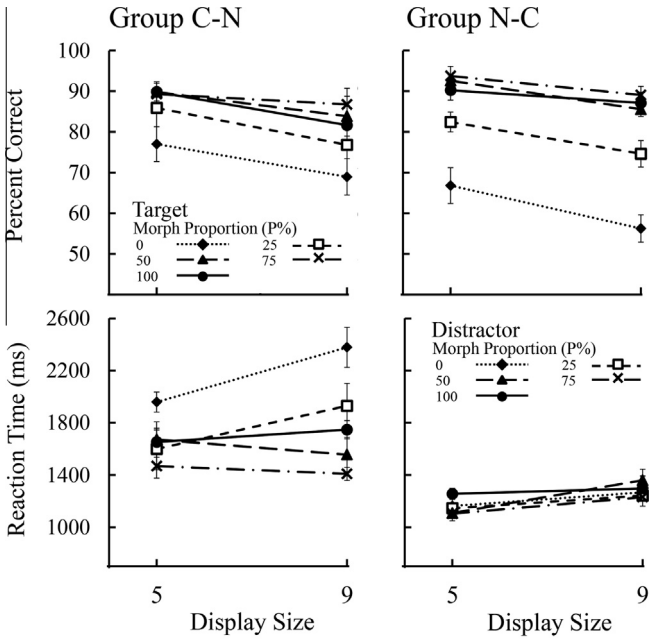

Fig. 5. Mean search accuracies (top panels) and reaction times (bottom panels) for display sizes 5 and 9 in the first two 2-session blocks, shown separately for the different proportions of the common component of targets in Group C-N and of distractors in Group N-C. The error bars show standard errors.

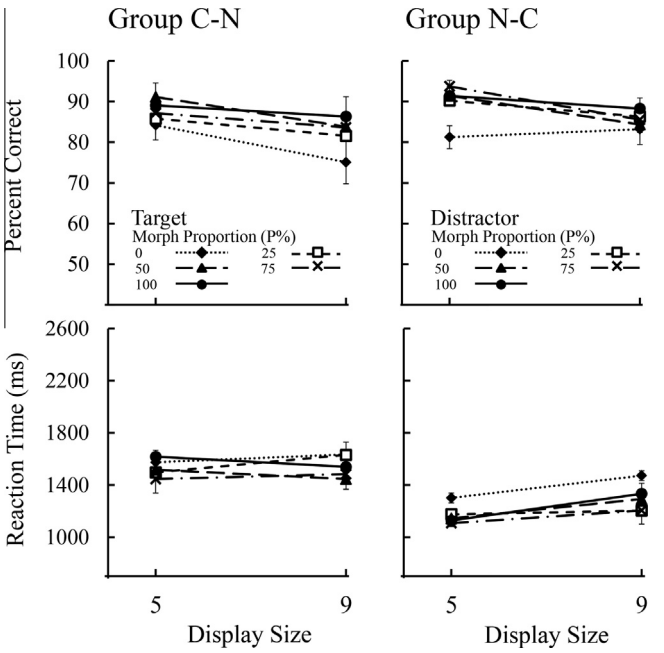

Fig. 6. Mean search accuracies (top panels) and reaction times (bottom panels) for display sizes 5 and 9 in the last two 2-session blocks, shown separately for the different proportions of the common component of targets in Group C-N and of distractors in Group N-C. The error bars show standard errors.

Namely, the pigeons efficiently searched for the category nonmembers among the novel members of the distractor category, including the original faces A, B, C and D used as the item-specific components. These results suggest that the common component of the old distractors (P of Faces AP, BP, CP, and DP) was not critical for the efficient search shown by the pigeons in this group.

RT of error responses. In Group N-C, error responses significantly increased with the P% = 0 and P% = 25 distractors to an extent that allowed us to analyze error RTs. The pigeons tended to respond more quickly when they made error responses to these novel distractors (1049 ms on average at DSs = 5 and 9), compared with the RTs of correct responses (1204 ms on average at DSs = 5 and 9). A paired two-tailed t test found that the difference in RT between the correct and incorrect responses on these trials approached significance, $t(15) = 1.942$, $p = .071$, Cohen's $d = 0.66$ ($N = 16$; 4 pigeons × 2 morph-proportions × 2 DSs). Although the difference was not statistically reliable, it appears that the pigeons responded impulsively to these distractors.

3.2.2.2. Searches in last test sessions. Fig. 6 shows the mean accuracies (top panels) and RTs of correct responses (bottom panels) in the last two 2-session blocks (Blocks 7 and 8) averaged across four pigeons in each group.

Group C-N. The P% = 0 targets continued to produce relatively poor performance at DS = 9. The main effects [$F(4,12) = 4.38$, $p = .015$, $\eta_p^2 = .62$ for morph proportion; $F(1,3) = 13.64$, $p = .035$, $\eta_p^2 = .82$ for DS] were both significant. The interaction [$F(4,12) = 0.66$, $p = .633$, $\eta_p^2 = .18$] was not significant. Fisher's LSD revealed that the P% = 0 targets significantly decreased search accuracy, relative to the P% = 50 ($p < .01$), 75 ($p < .05$), and 100 ($p < .01$) targets.

Search slopes were shallow regardless of the proportion of the common component of the targets. The main effects [$F(4,12) = 1.83$, $p = .187$, $\eta_p^2 = .38$ for morph proportion; $F(1,3) = 0.04$, $p = .852$, $\eta_p^2 = .01$ for DS] and the interaction [$F(4,12) = 0.69$, $p = .613$, $\eta_p^2 = .19$] were not significant. Practice led pigeons to perform equally efficiently with the various targets having different proportions of the common component, including the P% = 0 and P% = 25 targets.

Group N-C. Practice also led these pigeons to perform accurately with the P% = 0 and P% = 25 distractors, compared with the early sessions. Neither main effects [$F(4,12) = 1.82$, $p = .177$, $\eta_p^2 = .39$ for morph proportion; $F(1,3) = 4.43$, $p = .126$, $\eta_p^2 = .60$ for DS] nor the interaction [$F(4,12) = 1.38$, $p = .297$, $\eta_p^2 = .32$] were significant.

A remarkable RT finding was that, although the pigeons continued to show quick responses, they responded relatively slowly to the targets when the common component of the distractors decreased to 0%. A two-way repeated measures ANOVA revealed that the effect of morph proportion [$F(4,12) = 8.02$, $p = .002$, $\eta_p^2 = .73$] was significant. The effect of DS [$F(1,3) = 0.73$, $p = .081$, $\eta_p^2 = .69$] approached significance, but the interaction [$F(4,12) = 1.45$, $p = .277$, $\eta_p^2 = .33$] was not significant. Fisher's LSD revealed that the P% = 0 distractors significantly increased RT, relative to the P% = 25 ($p < .001$), 50 ($p < .01$), 75 ($p < .001$), and 100 ($p < .01$) distractors. Practice enabled the pigeons to perform accurately with the P% = 0 distractors (the P% = 25 distractors, as well); instead, the absence of the common component in the P% = 0 distractors required the pigeons to take more time in correctly responding to the nonmembers. Recall that the pigeons tended to make impulsive errors to these distractors in the early sessions.

Comparisons of RT between the groups. For the both groups, all targets and distractors became familiar in later sessions. Nevertheless, the bottom panels of Fig. 6 show that the correct responses were still faster in Group N-C (1235 ms on average) than Group C-N (1538 ms on average), a tendency similar to that found with highly familiar target–distractor pairs (P% = 50) in the early sessions of this experiment as well as in Experiment 1. To confirm this finding, we performed a one–tailed, rather than two-tailed, t test (the previous findings allowed us to expect the direction of the effect). It was revealed that RT was significantly shorter in Group N-C than Group C-N; $t(38) = 8.54$, $p < .001$, Cohen's $d = 2.70$ at DS = 5, $t(38) = 4.23$, $p < .001$, Cohen's $d = 1.34$ at DS = 9 ($N = 20$; 4 pigeons $\times$ 5 morph-proportions in each group).

3.3. Discussion

Group C-N replicated the findings of Ohkita and Jitsumori (2012). Specifically, pigeons efficiently searched for the familiar members of the category (the P% = 50 targets) and the efficacy transferred immediately to novel exemplars with a common component exceeding 50%, including the original face (Face P) used as the common component. The search efficiency dramatically decreased as the common component declined from the 50% level. The pigeons then developed efficient search for these poor exemplars through practice. Ohkita and Jitsumori (2012) explained the effect of practice by assuming development of automatic processing of the individual poor exemplars, supplementary to the search promoted by the common component of the learned category.

The Group N-C pigeons showed a marked decrement in accuracy when the common component of the distractors decreased (the top-right panel of Fig. 5). A given P% = 0 distractor (a P% = 25 distractor, as well) could be similar to some but not all the distractors used for training (for example, Face A is similar to the composite face AP but not to BP, CP, and DP). We therefore speculate that these novel distractors were highly activated in search displays, perhaps as much as the targets on some trials, where the pigeons were inclined to respond impulsively to these stimuli. In later sessions (the top-right panel of Fig. 6), the pigeons learned to reject these stimuli by practice.

An important finding in Group N-C is that correct responses were generally fast, irrespective of the proportion of the common component and DS. If the common component of the distractors guided the pigeons' attention away from the distractors, then correct responses should be slow when the common component decreased. But, this was not the case. We may conclude that the search performance is not accounted for by the negative-guidance by categorical distractors. How can we explain the surprisingly efficient search for the category-unspecified nonmembers? This will be discussed in Section 4.

4. General discussion

We used an artificial category characterized by a common component in the form of Face P which served as the basis of morphing transformations to create a variety of exemplars of a facial category. Our findings from the Group C-N pigeons confirmed the conclusion of Ohkita and Jitsumori (2012) that a common component (i.e., such as P) guides the pigeons' attention to the category members. In contrast, the Group N-C pigeons did not search for the lack of the common component of the categorical distractors; the efficiency levels neither decreased nor increased as a function of proportion of the common component in Experiment 2. It appears that pigeons learn categorical information of "what they are looking for" but not of "what they are *not* looking for." Visual fields in nature are full of miscellaneous objects of not a few categories that may differ depending on search fields, seasons, and many other factors. The present finding fits with our intuition that animals do not waste cognitive resources on learning distractor categories in nature.

Ohkita and Jitsumori (2012) reported that unpublished data revealed that the reversal of target–distractor roles produced severe interference for the pigeons trained in the C-N task; the pigeons persistently responded to the categorical distractors that had been previously used as the targets. Ohkita and Jitsumori (2012) also reported that, when the same pigeons proceeded to heterogeneous training (i.e., a target was embedded in several different distractors in a display), they performed accurately from the beginning of the training. These results suggested that their pigeons, as well as the Group C-N pigeons in the present study, did not solve the search task by developing a response rule, such as "peck one unique item that differs from the others in a display". The target surrounded by the identical distractors could be the "odd item" in a display, but the pigeons did not use the odd-item search strategy.

Pigeons have been successfully trained in odd-item search tasks (e.g., Allen & Blough, 1989; Blough, 1989, 1993; Pearce & George, 2003). In these studies, all items served equally as targets and distractors. Therefore, the targets were not defined as specific items, but rather as the unique items in the displays. For the pigeons in the study of Ohkita and Jitsumori (2012) and the Group C-N pigeons in the present study, the target was drawn from a set of category members, all of which never appeared as distractors throughout the experimental sessions. Therefore, the pecks made to the category members (correct responses) were rewarded by foods, but

those made to the category nonmembers (incorrect responses) were not. The extensive fixed-item training with a relatively small number of targets might have strongly interfered with these birds learning to search for the "odd items" in the displays.

Similarly, it is unlikely that the Group N-C pigeons searched for a unique item in a display. Actually, in the early test sessions of Experiment 2, not only Group C-N but also Group N-C showed a marked decrement in accuracy when the proportion of the common component decreased to 0%, while they performed accurately when it increased to 100% (the top panels of Fig. 5). Recall that the category was created individually for each pigeon in a group. So, a display containing the P% = 100 face (Face P) for one pigeon was used as a display containing the P% = 0 face (Face A, B, C, or D) for another pigeon. Therefore, physical similarity between target and distractor for these displays were counterbalanced across pigeons in each group. Because the target–distractor similarity is crucial to the search for an item that differs from the others in a display, the odd-item search strategy does not account for the beneficial effect of the novel displays containing the P% = 100 face. There is no good reason to suppose the odd-item search as an account of the surprisingly efficient searches shown by the Group N-C pigeons.

Why did Group N-C continue to show RTs faster than those of Group C-N, even when the target detections of the latter group became fast, automatic, and effortless by practice? We should note here that the categorical distractors might have an effect on the processing of the targets rather than on the time to reject distractor(s) in a display. This is because categorical distractors markedly decreased overall search time, irrespective of DS (compare the bottom panels of Fig. 6). In addition, Group N-C generally and consistently performed better than Group C-N from the early stages of training in Experiment 1. This means that the effect is not attributable to perceptual learning (e.g., Goldstone, 1998) nor practice (e.g., Shiffrin & Schneider, 1977). We suggest that the categorical distractors might have an effect on the purely perceptual processing of the target.

One might argue that the facilitative effect of the categorical distractors parallels the distractor-repetition effect (e.g., Geyer, Müller, & Krummenacher, 2006; Kristjánsson & Driver, 2008; Kristjánsson, Wang, & Nakayama, 2002). A number of studies in humans have shown that overall search time is faster when a given distractor type repeats from trial to trial than when the distractors differ over trials. Yet, as far as we know, no visual search study has explored the effects of distractor–distractor similarity on consecutive trials. We may expect, however, that the effect, if any, would be much weaker than a repetition effect involving the repeated presentation of the same distractor. Wolfe et al. (2004) used categorical pictures of real objects for humans in search tasks in which the target is specified just prior to the appearance of the search display on each trial. Search was efficient when target identity was cued with a picture that exactly matched the target but the effectiveness of cues diminished when they only specified the target category. Blough and Lacourse (1994) trained pigeons to search for alphanumeric characters in tasks of sequential priming and observed results indicating that pigeons' attention depends less on information provided by the immediately preceding trial (i.e., bottom-up priming) but seems to be directed by a top-down process that uses advance information, such as relative target frequency, as summarized over long sequences of trials (see also Blough, 1996). These studies examined the repetition effect of targets rather than of distractors. Considering these findings, however, the surprisingly efficient search in Group N-C may not be fully accounted for by a hypothesis based upon negative bottom-up priming for the categorical distractors.

An alternative account is that the categorical distractors may have helped pigeons to verify that the detected item is in fact a target differing from the retrieved memory traces of the distractors that they correctly rejected or incorrectly responded on recent trials. This account resembles the episodic memory model proposed by Hillstrom (2000) to explain the target-repetition effects in visual search in humans. It predicts slow RTs with the P% = 0 distractors, because each of these distractors (i.e., the item-specific component face A, B, C, or D) would have minimal net-similarity to the distractors that occurred on preceding trials. The finding in the later sessions of Experiment 2 that the pigeons showed relatively long RTs with the P% = 0 distractors is consistent with this prediction. However, this was not the case in early sessions, where pigeons showed similarly efficient searches irrespective of proportion of the common component of the distractors.

Finally, we suggest that the search tasks used for the two groups are not truly symmetric (see Rosenholtz, 2001, for a similar argument). Variability of the distractors across trials is smaller, in other words, cross-trial similarity is larger, for Group N-C than Group C-N. Therefore, the search for targets among distractors having a larger cross-trial similarity is easier. The similarity among the targets also differed between the groups but predicts a result in the opposite direction. Accordingly, the search asymmetry is attributed to the asymmetry in distractor–distractor, rather than target–target, similarity across trials.

This idea is in a good agreement with the finding that search asymmetry favored the search for an artifact among animals in the study by Levin et al. (2001) in humans. In a task presenting a series of searches for a randomly selected animal target among a mixed set of artifact distractors, and vice versa, they found that searches based on categories are highly efficient. Yet, search slopes for the artifact targets were generally shallower (i.e., more efficient) than those for the animal targets. The stimulus variability was much smaller in the animal stimulus set than in the artifact stimulus set (see Fig. 1 in Levin et al., 2001). They argued that distractor–distractor similarity within displays could be one of the factors that determined the search efficiency. However, it has been well known that the distractor–distractor similarity presented as a within-display variable has a minimal impact when target–distractor similarity is small, where search is always highly efficient (Duncan & Humphreys, 1989). Because searches based on categories were highly efficient in the study by Levin et al. (2001), we suggest that cross-trial distractor–distractor similarity, rather than within-display distractor–distractor similarity, could be one of the factors that determined the search asymmetry favoring search for an artifact among animals. The category *animal* in general may have a higher family resemblance than the category *artifact* comprising of miscellaneous man-made objects (Rosch & Mervis, 1975; also see Makino & Jitsumori, 2007, for family resemblance of artificial categories).

The categorical distractors appeared across trials for Group N-C and this may have contributed to their potential for marking targets as highly distinguishable from distractors. In this case, targets would stand out from the global contextual background, thereby becoming highly salient within each search display. Then, our finding in pigeons is consistent with a finding in humans that deviants (i.e., category-unspecified nonmembers in the present study) among standards (i.e., the category members) are easy to detect (e.g., Treisman, 1991; Treisman & Gormican, 1988; also see Kayaert, Op de Beeck, & Wagemans, 2011, for a prototype-deviation asymmetry). That is, a category-unspecified stimulus might have specific feature(s) marking its deviation from the category members that are more or less similar to one another. However, the effect of cross-trial distractor–distractor similarity proposed here should be systematically and more fully examined in future.

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